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THESIS

THREE-DIMENSIONAL DISPLAY
OF
SYNOPTIC SCALE WEATHER DATA

by

Robert F. Crosby

June 1986

Thesis Advisor: P. A. Durkee

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Three-Dimensional Display of Synoptic-Scale Weather Data

by

Robert F. Crosby
Captain, United States Air Force
B.S., Southern Illinois University, 1981

Submitted in partial fulfillment of the
requirements for the degree of

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from the

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June 1986

ABSTRACT

This thesis develops a technique for the three-dimensional (3-D) display of clouds, topography and atmospheric surfaces on an image and graphics analysis system. Cloud heights were estimated from infrared satellite imagery. Software was written to translate two-dimensional gridded data height fields into gray shade images. Existing 3-D display software was modified to use the data images as input. Potential temperature and 500 mb surfaces are presented as examples of possible fields for analysis in 3-D. The software was further modified to expand the geographical area enclosed in the final 3-D images. These images were used to produce 3-D displays of topography, clouds and atmospheric parameters. The relationships between atmospheric surfaces and cloud structures can be more clearly seen in the 3-D representations. With modifications to increase the resolution of the 3-D displays, improved understanding of the atmosphere can be expected.

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I. *INTRODUCTION*

During the past 40 years, significant advances have been made in the modeling and understanding of atmospheric processes. Numerical techniques have advanced at a pace closely linked to the development of more sophisticated computer systems (Shuman, 1978). Remote sensing of the atmosphere has the potential to further the accuracy of numerical models and meteorological prognoses by providing more complete data bases. However, one area that does not appear to have advanced in like manner is the graphical and visual modeling of the atmosphere.

For most of the past four decades, meteorologists have depended on two-dimensional representations of atmospheric variables. Surface and atmospheric data are plotted either by computer or manually on varying sizes of surface maps. On each map is overlayed wind, pressure and/or temperature information at some vertical level. This may be of observed or forecast (predicted) patterns. The individual meteorologist must then keep track of these various layers by mentally overlaying them. If the size of the maps agree, it is sometimes possible to physically overlay transparent versions. This stacking process leads the educated eye to make associations between the changes at various levels.

A surface front, for example, may be strongly associated with an upper-level trough. A developing area of severe thunderstorms is usually the result of a very complex interaction between dry and moist air low in the atmosphere, the jet stream, surface heating and upper-level troughs. The numerical models which generate these charts have improved, but their output is still in the two-dimensional (2-D) map form.

The need for these models is clear when instructing students. The models are used to assist students in conceptualizing the 3-D nature of the atmosphere and the interrelationships of its constituents. Three-dimensional (3-D) constructions have been limited mostly to tedious, artistic renderings produced by hand, or physical models constructed from plastics. Advanced 3-D computer techniques for representing the environment have become available only in the past 10 years.

Attempts have been made to use stereo techniques to assist users in perceiving a more complete representation of the environment (Hasler *et al.*, 1981). In the stereo technique the viewer is looking at two images simultaneously: the original image in red and a shifted computer generated blue-green version of the image. In the shifted

image, each picture element (pixel) pixel is moved to the right of its real position by a distance that will correspond to the height changes (depth) in the displayed field. The viewer wears colored lenses to properly sense the depth in the field. A blue-green lens covers the left eye and a red lens covers the right. Each eye then sees one of the two images, the "real" pixel positions, and a shifted pixel position. The result is a perception of depth.

Three serious limiting factors affect the use of this type of product. First, only a very small part of the total satellite data base is processed for stereoscopic display. The user is not free to construct and view pictures of his or her designation. Second, the user must wear special glasses to view the images. Even with these lenses, it still requires some interpretive skill on the part of the user to achieve the proper sense of depth in all representations. Third, the product is static and cannot be manipulated by the viewer. Inherent in research and operational activities is the requirement that the product be as dynamic as possible; that it can be manipulated with as much speed as possible to test various hypotheses.

The products used in meteorology require the user to establish the proper 3-D relationships from 2-D products. By using techniques originally designed for mechanical engineers and architects, computer displays can be produced which place atmospheric data in a 3-D perspective.

A first step in this direction for meteorology was taken at Colorado State University (CSU) (Meade, 1985). Based on a 3-D computer display program MOVIE.BYU, originally developed at Brigham Young University, subroutines were added which allowed the construction of models of clouds over a topographic surface. After modification, it was renamed MOVIE2. The input was a combination of infrared and visual satellite data from GOES satellites, plus a digitized topography of the continental U.S., from the Defense Mapping Agency (DMA). The infrared imagery provided cloud top height information while the visual data were used optionally to shade the resulting 3-D structures. The program, as it existed then, allowed only the display of a 4.7 by 4.7 degree latitude area.

This areal limitation has been removed here. 3-D displays can now be produced for areas from as small to as large as desired. However, if the full resolution of the data for clouds, topography and atmospheric data surfaces were used, the run times for production of the 3-D images would be significant. The method used to overcome this problem will involve a simple averaging of picture elements. This process will increase

the number of pixels averaged together as the size of the selected area increases. This will reduce the effective resolution so that it holds the image content to a size which the MOVIE2 software will manipulate in a reasonable amount of time.

Utilizing the capability of the GEMPAK software , developed at the Goddard Space Flight Center and residing on the NPS VAX 11/780 computer, standard vertical weather measurements (rawinsonde data) can be plotted and gridded. These gridded data sets can be of either observed or derived quantities such as the lifted condensation level, stability indices, constant pressure surfaces and constant potential temperature surfaces. Once gridded, these data should then be transformed into a continuous tone gray-shade image. The image then can be displayed on graphics devices similar to the COMTAL Vision 1 at NPS. This image can be manipulated and displayed, simultaneously with cloud structures, by using MOVIE2 software. The combined display is expected to greatly assist researchers in viewing large mesoscale and small synoptic-scale systems. Further, it should enhance understanding of the relationships between various atmospheric surfaces.

It is the intent of this thesis to make a second step towards the development of a tool which research, and eventually the general meteorological community, can use. The technique developed in this research will allow for the near real time display of integrated topography, clouds and other atmospheric information in 3-D. These, combined with conventional data display techniques, will lead users to quickly extract information about the state of the atmosphere.

II. *SOFTWARE*

There are four main groups of software used in the construction of the 3-D models: GEMPAK, NAVGEN, GRIDIMG, and MOVIE2. These programs and program packages take raw satellite, rawinsonde and mercator projected topography data, and combine them into a unified display of clouds, topography and atmospheric variable surfaces. Although the manner in which the final 3-D image is produced is cumbersome, future refinements to this sequence are expected to greatly simplify the procedure. The flow diagram (Fig. 2.1) traces the processing of data through input to the 3-D display software.

A. GEMPAK

GEMPAK is a software package developed at the NASA/Goddard Space Flight Center (desJardins *et al.*, 1981). It consists of a variety of utility programs designed to operate on either surface or vertical sounding (rawinsonde) data files. It allows the user to create two-dimensional graphical displays of reported or derived atmospheric variables. It is menu driven, provides help files, and has a complete instruction manual for reference. Only a small part of its capabilities were used in preparing data for eventual 3-D display. Four GEMPAK programs were used: OAGRID, SNBNANL, GDLIST, and REMAP.

1. *OAGRID*

The program OAGRID produces a gridded data file to accept output later from the program SNBNANL. OAGRID reads a specified input vertical sounding or surfaces data set, or a subset specified by the user. It produces an evenly spaced, gridded field for one or more parameters (e.g., heights, temperatures, lifted condensation levels, etc.).

2. *SNBNANL*

Having established a suitable output file with OAGRID, the actual objective analysis is done by the program SNBNANL. It performs a Barnes objective analysis on the input data (Barnes, 1964). This produces data at evenly spaced locations. This step is necessary since rawinsonde balloon sounding launch sites are not located at grid points.

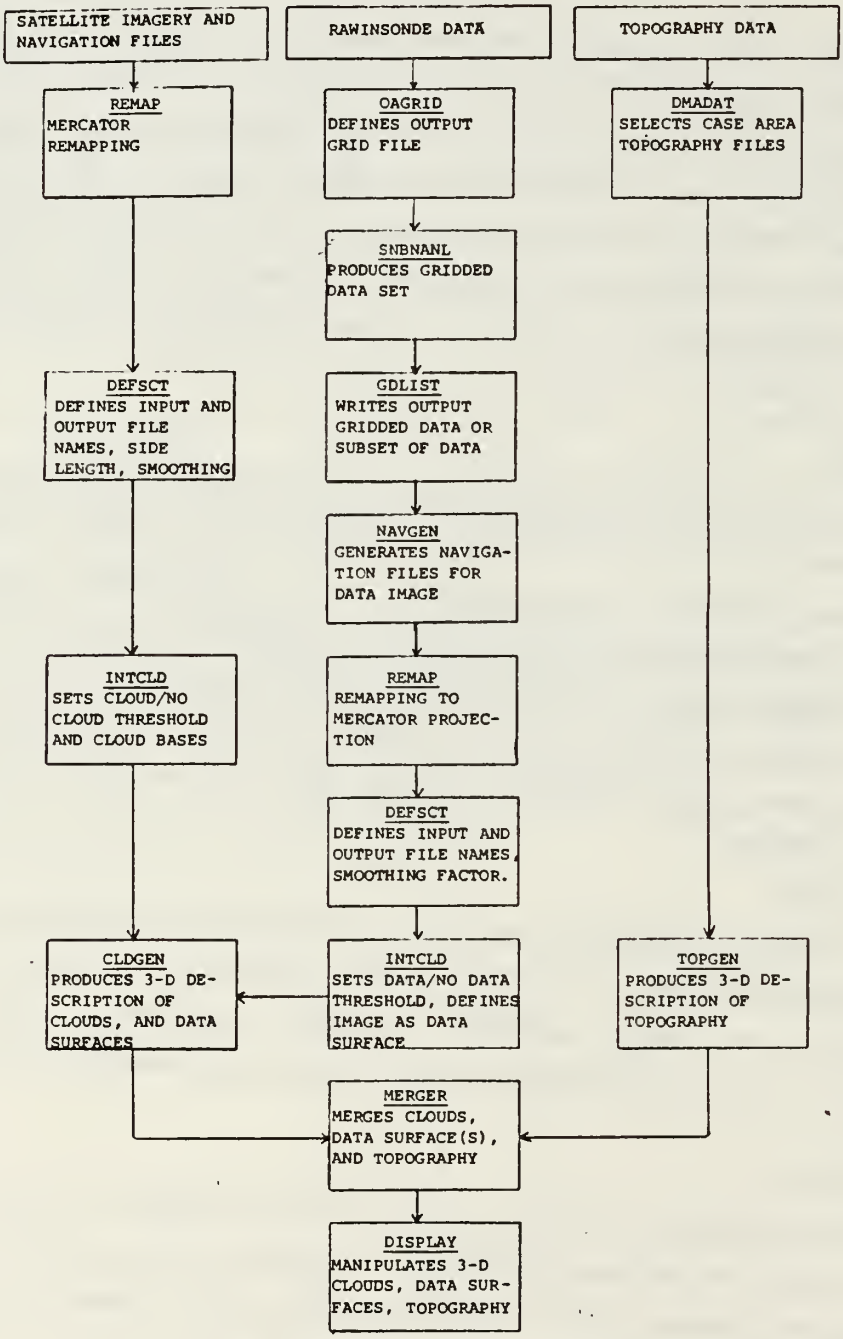

Fig. 2.1 Data Processing Flow Diagram.

3. *GDLIST*

This program allows the user to copy the data output from SNBNANL to another disk file, the terminal screen, or to a printer. The user can have any or all of the gridded parameters created in SNBNANL sent to these devices.

4. *REMAP*

The GEMPAK program REMAP converts 512 X 512 pixel satellite or atmospheric data images into various types of map projections. The image, representing infrared radiance values, is input with the corresponding navigation files; one file each for the latitude and longitude of image pixels. It is a menu driven program prompting the user at each step for input and output file names, projection type, and borders (if any). The resulting image is then availble for use as input to the MOVIE2 programs.

B. GRIDIMG

The next step was the development of GRIDIMG which uses the gridded data file as input and performs interpolation between adjacent grid points in both the x and y direction (bilinear interpolation). The interpolation allows a continuous tone gray shade image to be produced. Each shade represents a different height value where the atmospheric variable occurs. In order to assign the proper range of gray shade values and prepare the gridded data file, the user must examine the maximum and minimum heights in the data file. The maximum and minimum gray shade must be entered to provide a range of values to assign to grid point heights. Also, the grid dimensions (17 X 17, 12 X 12, etc.) and number of times the interpolation is performed, per image line, must be added. These values are then converted into the IR radiance count values associated with those heights, on a representative rawinsonde sounding.

C. NAVGEN

Next, NAVGEN was written so that output gray shade images from GRIDIMG would have navigation files. These files allow conversion, through REMAP, of the image into mercator coordinates. It creates the navigation files based on the input dimensions of the area contained in the output file from GRIDIMG. It produces two output files describing the latitude and longitude of every other pixel on a line of the image. This is done by matching the data point heights to the temperature at that height on a rawinsonde sounding. This temperature is converted into an IR radiance value (gray shade) using a standard GOES satellite calibration table.

D. MOVIE2

The MOVIE2 software allows the user to create 3-D, mathematically defined structures on a computer (e.g. VAX 11/780) for display on a computer graphics device (e.g. COMTAL, Tektronics, PC, etc.). It is a complex general application program allowing a user to create 3-D images by inserting the parameters necessary to define the dimensions of a structure. The structure's computer representation then can be manipulated by issuing specific commands. The shape can be rotated, enlarged, colored and separted into its various components.

The CSU developed user software includes a variety of programs which allow the translation of continuous tone images, in 256 shades of gray from black (shade 0) through white (shade 256). The CSU user programs DMADAT, TOPGEN, DEFSCT, INTCLD, CLDGEN and MERGER were added to allow the display of digital satellite data rather than engineering or architectural data, for which it was first written (Meade,1985). DISPLAY, UTILITY, SECTION, TITLE, MOSAIC, COMPOSE and UPDATE are the original FORTRAN programs which made up the original MOVIE.BYU software collection. As DISPLAY is the main program and can be used independent of the others, this program was used to display the 3-D images.

1. *DMADAT*

This program allows the user to select a subarea of the data contained on the DMA topography data tape. Based on the user's answers to prompts concerning the location and size of the desired area, DMADAT reads in the appropriate tape records. The input data are converted into gray shades, corresponding to temperature and vertical height, and writes the output image data to a scaled topography file. At present, the area selected can range from 1 X 1 degree up to 20 X 20 degree areas.

2. *TOPGEN*

The DMADAT output file must be converted into a form useable by the 3-D DISPLAY software. TOPGEN performs this function by converting the input topography image into a mathematical description of the data. It requires that the user enter the portion of the topography image to be included in the DISPLAY readable file. This can be either the entire image or a subset. The number of polygons desired, on a side of the 3-D structure, and a vertical height exaggeration factor are entered. The output file may be displayed either by itself, or merged with clouds and atmospheric surfaces.

3. *DEFSCT*

The program DEFSCT keeps track of which files have been requested for use in the final merged cloud and topography model. It contains information on the side length selections for clouds, topographies and atmospheric surfaces as well as the name of files to be used for input and output. Before execution of this program, the output file DEFSCT.DAT must be deleted so that the program does not maintain values selected by the user describing other previous 3-D image constructions (side lengths and file names). DEFSCT is executed after TOPGEN and before any other operations are performed on a cloud or upper air data image file (Meade, 1985).

4. *INTCLD*

Cloud top heights can be determined from the infrared (IR) temperature of cloud tops by converting the gray shade to the corresponding temperature. The temperature is then converted into a height by comparing it to the heights and associated temperatures on a representative rawinsonde sounding. These z-axis heights are included in the file to be read later by the MOVIE2 software. The x and y-axis extent of a cloud are determined by a software comparison of the cloud/no-cloud threshold value set by the user.

In the program INTCLD the cloud/no cloud threshold sets the value at which the software should begin to consider pixel gray-shades to represent clouds. It is entered in response to queries by the CSU program INTCLD (Meade, 1985). When a meteorological variable surface is to be produced, a value of -999 is entered in response to the question of base height. This entry sets the base and top of the layer at the same level, resulting in a curved plane having no vertical thickness. This program reads each line of the input image file and averages the pixel values together to produce smoothed image files. A limit of three levels of clouds and/or atmospheric surfaces currently exists in the software. Two files for each cloud level are produced storing information on the base level of the image and horizontal extent within the cloud or surface.

5. *CLDGEN*

The program CLDGEN produces the files that can be merged together with topography files from TOPGEN and can be read by DISPLAY. In creating a meteorological upper air surface, rather than clouds, the DEFSCT.DAT file must first be deleted. This is necessary because CLDGEN will attempt to search for files that have not been created in INTCLD when using the -999 cloud base option. The inputs for

this program are the output files from INTCLD. The user provides the names for these files, CLDGEN reads the input data files and produces the output scaled cloud or upper-air surface files.

6. *MERGER*

The program MERGER combines the topography and cloud or surface files into a single "cloud topography model" file. If an upper-air surface is merged with topography, the DEFSCT.DAT file must be deleted again, as it is recreated at each processing step in the CSU added programs. Once created, the output file can be used as input to the program DISPLAY.

When the final model includes clouds, topography and an upper-air surface, DEFSCT and INTCLD are run separately for each layer. The upper-air surface description replaces one pair of files describing an unused cloud layer in the cloud model files. When MERGER is run the result is a combined representation.

E. DISPLAY

DISPLAY is a general purpose computer graphics display program for constructing polygonal representation of objects. It has the capability to produce either line or continuous tone image output (Christiansen and Stephenson, 1981a). There are 47 interactive commands which allow for changes to be applied to a previously created image or frame.

1. *Commands*

A set of 3-D images, once displayed by the program DISPLAY, is referred to as a frame. Within that frame each component is a numbered part (Christiansen and Stephenson, 1981a). By identifying an individual part of the frame, it can be manipulated. For instance, a frame may consist of three parts; the topography, a cloud and an atmospheric data surface. Any additional cloud or surface would be considered another part of the frame. Some of the 47 commands can be used to change the entire frame (colors, apparent distance, viewing angle) or may apply changes only to specified parts (Christiansen and Stephenson, 1981b). The ROTATE command rotates all the parts within the frame by a specified number of degrees on a given axis. DISPLAY does this while maintaining the proper relationship between the components of the frame, just as if the observer were to change his or her viewing position. When several parts are introduced into a frame, coloring individual parts becomes a useful aid in recognizing them after their positions have changed.

2. *Geometry Files*

DISPLAY can use four types of data files: geometry, displacement, scalar function and contour. For purposes of this thesis, only geometry files were used. Each geometry file must contain a complete description of the objects to be handled by DISPLAY. The description includes:

- Control variables representing the number of parts that will appear in the frame, the number of connection points (nodes) between line segments, and the total number of edges in all the individual parts. A square plane consisting of none small, four-sided panels would have 36 edges
- A connectivity array associating the nodes with each small element, or panel, of which they are a part
- The coordinate array storing the location of the panel connection points (nodes) in Cartesian coordinates
- The parts array, a two-dimensional matrix containing the upper and lower limits of the connected panels in a part.

III. *CASE DATA AND PROCESSING*

Selection of the case to demonstrate synoptic-scale weather features in 3-D, was based on a review of weather satellite images during the period 15 - 17 May 1986. Also, the availability of the corresponding rawinsonde data played a large part in the case selection. As discussed above, three primary types of data are required: satellite, rawinsonde and topography.

A. SATELLITE DATA

An infrared satellite image from the GOES satellite at 2300 hours Greenwich Mean Time (GMT) on 15 May 1986 was used. The area selected includes the south-central U.S. in an area bounded by 25^0 and 45^0 N latitude, and by 80^0 and 100^0 W longitude. The infrared satellite image on that date indicated well developed cloud structures, with good vertical extent, in a cyclonic weather system. The image was provided by the Naval Environmental Prediction Research Facility (NEPRF), Monterey, California. The images were of 4 n mi resolution at the subsatellite point. This enlarges to approximately 6 n mi resolution at 40^0 N. That is, the smallest picture element (pixel) distinguishable represents a 6 n mi square of the earth. The average radiance from the pixel area is represented as a single brightness value.

Included with the image were two navigation files. The navigation files contained the information necessary for a computer program to associate each pixel with the latitude and longitude of its location. The raw image was in the satellite's coordinate system. Therefore, this could be converted into a mercator projection for use in the MOVIE2 manipulations.

B. RAWINSONDE DATA

Computer files containing vertical atmospheric sounding data for 0000 GMT 16 May 1986, over the continental U.S., were used as inputs to the programs GDFILE, SNBNANL, and GDLIST. These programs produced evenly spaced, 17 X 17 point (60 n mi spacing) gridded data files containing 500 millibar (mb) pressure and constant potential temperature (330^0 K and 320^0 K) surfaces. The 500 mb pressure surface, occuring at roughly 18,000 feet, is a standard level used by meteorologists to determine the location and intensity of significant weather features. The constant potential temperature surfaces can also provide information on the stability of the atmosphere.

The gridded data files contain tables of numbers giving the height at which the given surface occurs in the atmosphere. MOVIE2 requires gray shade continuous tone images as input. To create the continuous tone image from these data files they were processed by the program GRIDIMG. The output of GRIDIMG is a 512 by 512 pixel continuous tone image.

The data images output by GRIDIMG were in a cylindrical map projection. The program NAVGEN was used to create the navigation files for the images. The navigation files and image were used as input to the GEMPAK program REMAP to produce mercator projected images.

C. TOPOGRAPHY DATA

The topography data files were obtained from the Defense Mapping Agency (DMA). These files provided elevation data over the continental U.S. in 30 second (1/120 degree) intervals. These data were read by the MOVIE2 program DMADAT (Meade, 1985). A subset of the data selected was chosen to coincide with the remapped satellite and atmospheric data images. The output from DMADAT was a gray shade image in a mercator projection. This image was used as input to the program TOPGEN, which translated the image into a 3-D mathematical description. The output from TOPGEN was available for immediate use by DISPLAY, or for merging with cloud and parameter surfaces.

D. DATA PROCESSING

1. *Satellite Imagery*

The raw, infrared satellite image (Fig. 3.1) is shown on the COMTAL image processor. This initial image enclosed an area much larger than was desired. The raw image was cropped down to a 20^0 latitude by 20^0 longitude area and was remapped into a mercator projection using the program REMAP (Fig. 3.2).

The remapped image contained a large amount of cloud imformation, unfortunately too much for the DISPLAY software. To reduce the number of clouds, only those with a pixel value of 160 or greater (-53^0 C) were selected. The hook shape of the occluded low in Figs. 3.1 and 3.2 is still clear after the majority of clouds are removed by setting the pixel threshold. The resulting image and 500 mb contours, overlayed on the remapped satellite image, is presented in Fig. 3.3.

2. *Atmospheric Parameter Data*

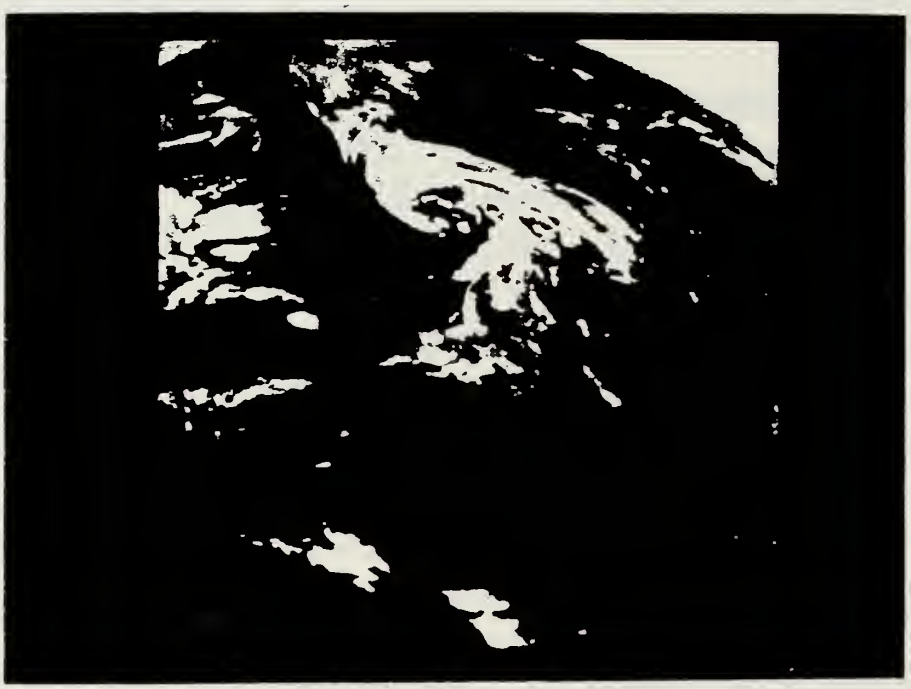

Fig. 3.1 IR GOES Satellite Image (Raw)
2300 GMT 15 May 1986.

Fig. 3.2 Mercator Projected Satellite Image
2300 GMT 15 May 1986.

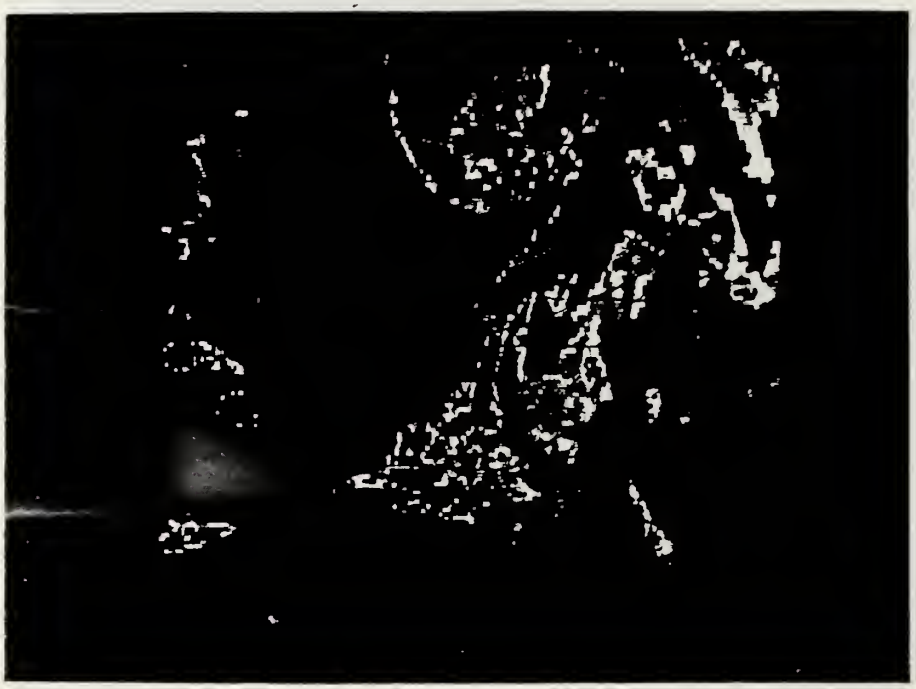

Fig. 3.3 Mercator Remapped Satellite Image,
500 mb Contours, and Enhanced Pixels (Pixel Value $\geq$ 160).

The two dimensional gridded parameter file contours are presented in relation to the satellite image and geopolitical boundaries in Figs. 3.4, 3.5, 3.6, and 3.7.

The height range of the 500 mb pressure surface (Fig. 3.4) is from 5640 to 5880 meters (m). The highest point on that surface is in the southwest corner and the lowest point is in the northwest corner. This height range, 240 m, is quite small compared to the surface area which is measured in hundreds of kilometers.

The 320^0 K and 330^0 K constant potential temperature surfaces (Figs. 3.5 through 3.7) show a much larger vertical variation than the 500 mb pressure surface. The 320^0 K surface ranges from a high of 9498 m in the northwest corner, to a low of 3165 m in the southwest corner. The 330^0 K surface ranges from a high of 11,150 m in the northwest corner and to a low of 6589 m in the southeast. Finally, Fig. 3.7 is presented, showing both the 320^0 K and 330^0 K surfaces. Using potential temperature surfaces, the relationship between frontal boundaries and cloudiness can be examined.

The parameter height fields were then processed by the programs GRIDIMG and REMAP to produce remapped continuous tone images for use as inputs to the MOVIE2 programs DEFSCT, INTCLD, CLDGEN and MERGER. The result were files that described the geometry of the 3-D structures in a form usable as inputs to the DISPLAY program.

E. DISPLAY PROCESSING

To demonstrate the information conveyed by the 3-D atmospheric displays, a series of frames were produced at various angles and apparent distances. The vertical height scale in each 3-D display was exaggerated by a factor of 50, to emphasize the vertical variations. Each figure produced consists of a continuous tone image and overlaying line graphic display, both from the same perspective. The overlaying process helps convey additional information on the spatial variation of the structure being viewed.

In each image, the location of the light source is selected to be either at infinity, in a given direction, or at the eye of the observer. This is entered during execution of the DISPLAY program using the command LIGHT. The user describes the color of each part withing the frame using the COLOR command (Christiansen and Stephenson, 1981b). The intensity of the reflected light from a panel, on a selected part, is dependent on the orientation of the panel. With a variation in the side structure of clouds or a height change on a data surface, the result is light returning to the viewer at different intensities, depending on the angle of a panel.

Fig. 3.4 500 mb Pressure Contours
and IR Clouds (Pixels ≥ 160).

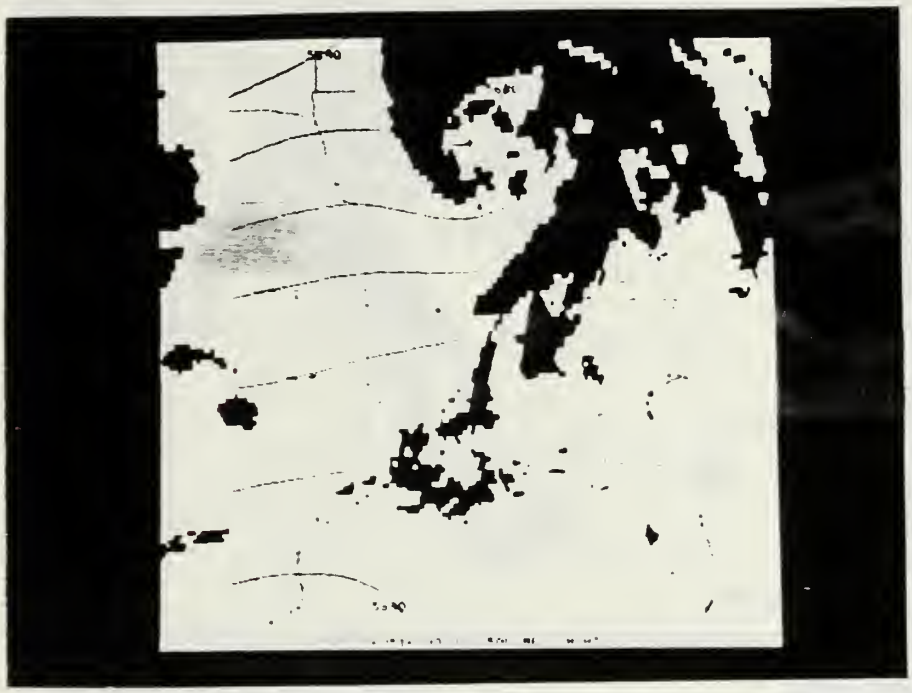

Fig. 3.5 320^0 K Potential Temperature Contours
and IR Clouds (Pixels ≥ 160).

Fig. 3.6 330^0 K Potential Temperature Contours
and IR Clouds (Pixels ≥ 160).

Fig. 3.7 320^0 K and 330^0 K Contours
and IR Clouds (Pixels ≥ 160).

Although a given data surface may be defined by a single color, varying brightnesses are reflected back. The result of these shade changes is that information about the structure of the surface is conveyed to the viewer which might otherwise not be apparent. To reenforce the changes in structure and depth, line graphic images were overlaid on the continuous tone images. This gives an added sense of depth due to the divergent and receding line segments.

In producing each of the 3-D displays, the cloud field is averaged. Clouds with pixel values of 160 or greater (Figs. 3.3 and 3.7) are smoothed. The result is a loss of the smaller cloud tops in the central and southern portions of the area. However, the hook shape is still evident in the 3-D displays (Figs. 3.10 and 3.13).

Fig. 3.8 is a 3-D display of the information contained in Fig. 3.4. In this display the data structures (frame parts) are viewed from the southern edge. This display places in proper perspective the 500 mb pressure surface, clouds, and topography.

To examine the topographic and parameter surface variations more closely, the apparent distance to the frame was reduced by one half (Fig. 3.9). In this view, the topographic variations are slightly more distinct. The 500 mb surface variations are basically indistinguishable, even with the factor of 50 applied to the vertical. To obtain a view which conveys more information about the 500 mb surface, an oblique view was produced, at the original distance to the frame (Fig. 3.10). However, here again the vertical changes in the 500 mb surface can barely be detected.

As described earlier, the constant potential temperature surfaces have considerably more vertical variation than the pressure surface. Figures 3.11 through 3.13 show the same perspective changes as with the 500 mb series. A comparison of Figs. 3.7 and 3.13 illustrates the significant increase in visual clarity and understanding of the relationship between the two potential temperature surfaces. Fig. 3.7 must be examined carefully and for some time before their relationship can be established.

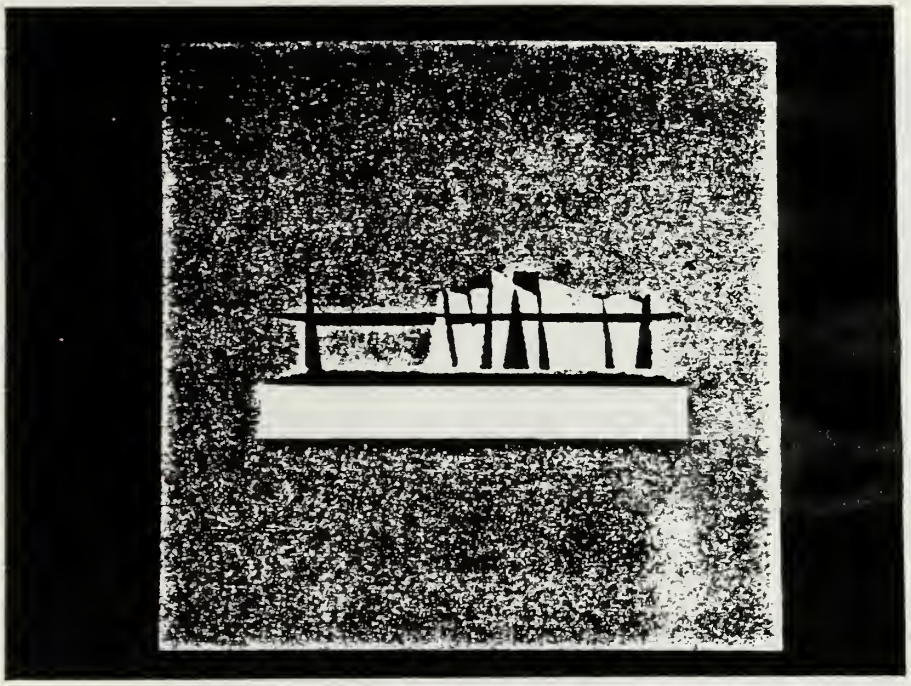

Fig. 3.8 3-D 500 mb Surface, Clouds and Topography
View From the Southern Edge of the Region.

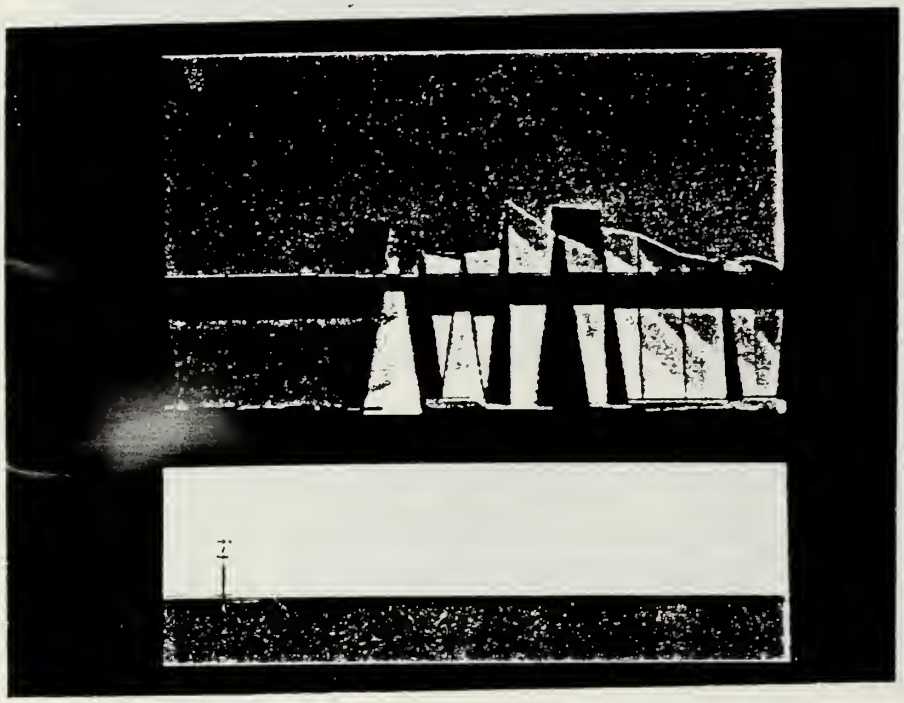

Fig. 3.9 Zoomed 500 mb Surface, Clouds and Topography
View From the Southern Edge of the Region.

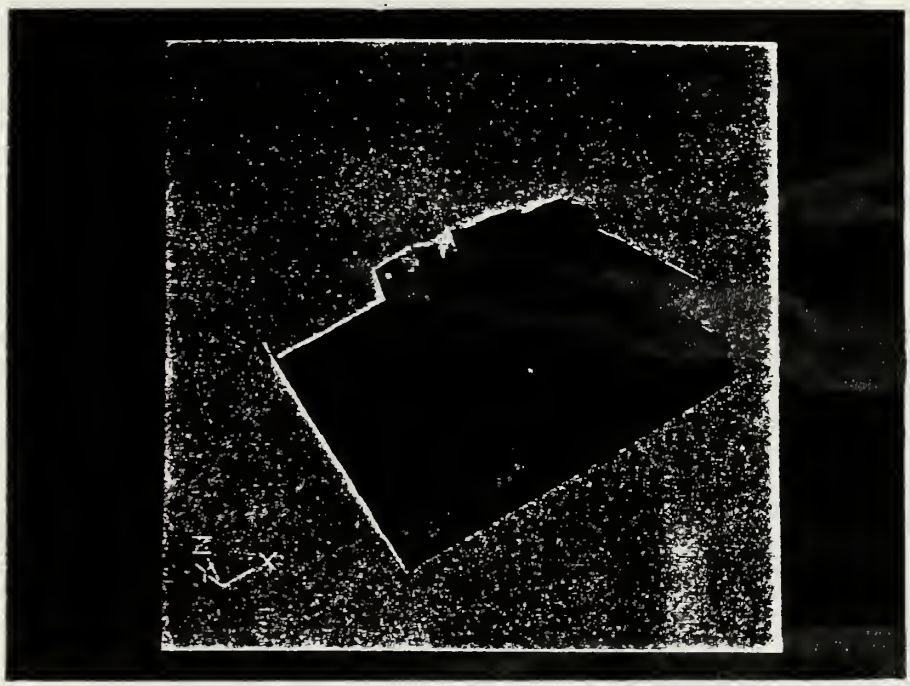

Fig. 3.10 Oblique 500 mb Surface, Clouds and Topography
View From the Southwest Corner of the Region.

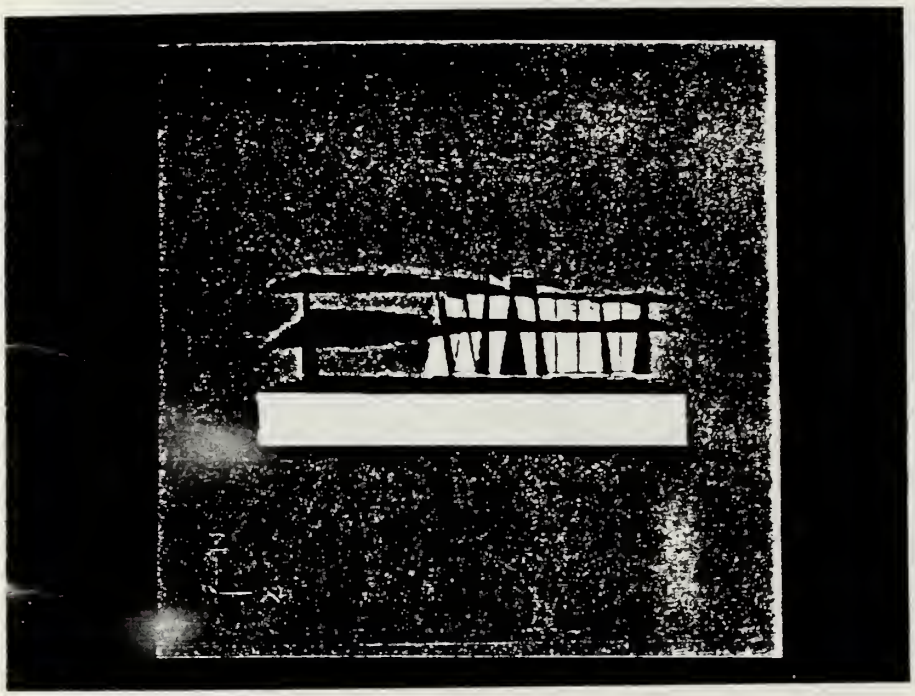

Fig. 3.11 3-D 320^0 K and 330^0 K Surfaces
View From the Southern Edge of the Region.

Fig. 3.12 Zoomed Potential Temperature Surfaces
View From the Southern Edge of the Region.

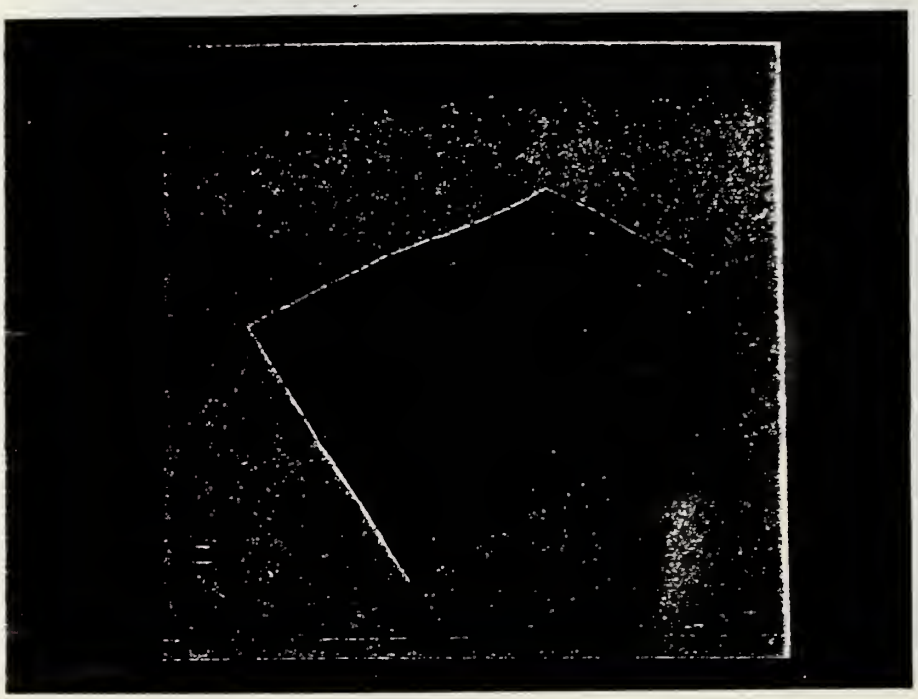

Fig. 3.13 Oblique Potential Temperature Surfaces
View From the Southwest Corner of the Region.

IV. *CONCLUSIONS AND RECOMMENDATIONS*

A. CONCLUSIONS

The series of 3-D displays of the atmospheric data, used in conjunction with conventional 2-D displays, provide another tool for use by meteorologists in their attempt to understand weather systems. These have application for the display of pressure surfaces. Those displays, with a series of vertical height exaggerations, could be instructive to students learning about the structure of the atmosphere. The information conveyed in an operational setting would be useful as an aid to flight briefings. Aircrews planning flights at constant pressure levels would see the relationships between their flight path and cloud patterns at that flight level.

Some data surfaces vary greatly in height over relatively small horizontal distances. The display of potential temperature surfaces shows the possible application of such models to atmospheric studies. This depends on the type of surface and intensity of the weather situation in which it occurs. Another type of surface that varies greatly in height are constant equivalent potential temperature surfaces. These include atmospheric moisture in their computation and are useful in locating frontal boundaries at various points both vertically and horizontally. However, at the present time MOVIE2 programs cannot adequately deal with points on the surface topography intersected by such isentropic surfaces.

Numerical weather prediction (NWP) models, whose output is the basis of much of present-day weather forecasting, predict a variety of surfaces which could be viewed from the three-dimensional perspective. This would convey added information about the behavior and structure of the various levels within the models. Both research and operational meteorologists would find this application useful.

B. RECOMMENDATIONS

After having developed the procedure for including data surfaces in these 3-D images and expanding the technique to a synoptic scale, it has become apparent that many improvements are possible. The current sequence and time for construction of these images needs to be improved. At present, a number of steps performed with much human intervention should be automated. This could be accomplished by establishing default or standardized processing parameters.

Prior to actual use in the DISPLAY software, the processing could occur as a result of program executions from previously constructed files. These files would control program execution, providing the information on input/output file names and settings required by each program to produce the file for input to DISPLAY. This would make it easier for users to employ the 3-D technique in case and model studies.

Within the program DISPLAY, several modifications are recommended. First, the axis triad, showing the location of the x, y and z axes, should include a vertical height scale along the z-axis. This would greatly improve the user's sense of height to width proportions. Second, an overlay of geopolitical boundaries within the 3-D image would aid in properly placing features with respect to surface locations. Third, an option could be included in the DISPLAY software allowing simultaneous construction and display of the line graphic and continuous tone images. As can be seen in the figures above, the combination of line and continuous tone images provides more information on the structure of clouds and surfaces than either alone. Fourth, an option to send constructed images to disk or tape files from within DISPLAY should be developed. At the current time, the user must exit the DISPLAY program abruptly to ensure that the 3-D images are not lost, as when normal exit from DISPLAY is used. Saving the 3-D images allows very rapid retrieval and would be easier to use in a looping process for time sequence examinations.

The CSU generated software allows for only three layers of data. That number could be raised, as long as the total number of parts in the DISPLAY frame do not exceed 27. A capability to process atmospheric data surfaces as unique parts, as opposed to modified cloud structures should be added to the programs DEFSCT, INTCLD, and CLDGEN. The program CLDGEN should be modified to set the base of pressure and other surfaces to equal the topography gray shade at intersection points. This would allow the display of any atmospheric surface, especially those whose computed elevations may be below the surface. The actual height would still be available in the grided data file and the displayed 3-D image would show intersection locations.

The hardware that presently produces the 3-D frames, a VAX 11/780 computer, is a time shared device. Each user has a "virtual machine", seeing what appears to be a computer devoted solely to that individuals task. In fact, it is working on a variety of tasks for different users, allocating its attention from one to another task. The construction of 3-D frames requires the use of a large amount of the VAX 11/780

memory. With the present system configuration it can take as little as two or as long as long as thirty minutes to construct a single 3-D frame. The recommended solution is to move the DISPLAY software, at least, onto an array processor. That device could do the complex matrix operations involved in image manipulations in much less time.

An increase in the resolution of the 3-D displays will allow active use by NWP modelers, researchers studying significant weather events and meteorology students. With some modification, oceanographic data fields could be used as input to the 3-D display technique.

Sophisticated 3-D display hardware is becomming available for researchers. Using the 3-D display data files as input, devices will be capable of letting users take real-time animated tours through the displays. This should lead to new techniques for the analysis of data that previously has been represented in only two dimensions.

APPENDIX A

SAMPLE PROCESSING STEPS

For those users who would like to produce 3-D images, the following lists of suggested processing steps is offered to assist. It is assumed that the reader is familiar with operating on the VAX 11/780 computer, using the COMTAL display, and using GEMPAK.

1. CLOUDS AND TOPOGRAPHY

- Extract the topography tape records using the MOVIE2 program DMADAT. The program DMA512, also in the MOVIE2 package, does not currently write out the correct header record and should not be used. The output from DMADAT is a file of your name choice with the extension ".STI".
- Construct the topography model using the output file from step 1 as input to TOPGEN. Note: Any vertical height exaggeration factor applied here will be also applied to subsequently developed cloud or atmospheric data plane. Output is a file with extension ".STM".
- Run the program DEFSCT using the ".STI" topography file and a cloud image file ".IMG" as input. Both a visible and an IR cloud image file can be used, or an IR image alone.
- In keeping track of the many files produced in this overall sequence, it is useful to use the same filename for each file. The distinction between various file types is made in the extension which the MOVIE2 software assigns to the output files. Also, the topography ".STI" filename and the ".CTM" cloud file name must match for them to be merged together later.
- The side length, smoothing factor and x,y coordinates of the top left corner of the TOPGEN and DEFSCT files must match.
- Run INTCLD using the previous steps' output files. Make sure that the cloud/no cloud threshold input value is a gray shade appropriate for the clouds you wish to display. If the threshold is set too low, this may cause too many parts to be included in the 3-D model (27 is the maximum number). Set the cloud bases to a level determined by examination of a representative rawinsonde sounding for the area.
- Run CLDGEN. No prompts should appear in this step.
- Run MERGER. No prompts at this step either. Note the number of clouds merged. This information is used later in DISPLAY to identify parts of the 3-D frame on which to operate.
- Run the DISPLAY program using the command "R MOVIE2".
- Once in DISPLAY, the user is prompted for an input file name. The response can be either the topography ".STM" file to a cloud topography model ".CTM" file.
- Within the DISPLAY software, commands can be referenced in the MOVIE.BYU Training Manual. However, examples of the responses to these commands are difficult to locate. When producing continuous tone color frames, the user must enter the COLOR and LIGHT commands and respond to a series of prompts. An example of the response to the COLOR command prompts appears below. User responses do not include the quote marks.

---Background---(Red,Green,Blue)---> > > "0,.7,.7"
---Parts---> > > "1,1 .6.4,.6"
----------> > > "2,5 0,.9,0"
----------> > > "6,6 0,0,.9"
----------> > > "7,7 0,.7,.7"

- After the next > > > prompt, the user enters a null entry.

---Standard Fringe---> > "Yes"
---Symmetric---------> > "Yes"

- Typical responses to the LIGHT command might be as follows.

---Light Source Number----------> > > "1"
---Light Source at the eye of the observer?----> > > "Yes"
---Light Source Intensity----------> > > ".8"
---Normal Parts Exponent----------> > > "1,7 .6"
---Highlight for parts...and exponent-------> > > "1,7 .6,6"

- After the last > > > the user sends a null entry.

2. CLOUDS, TOPOGRAPHY, DATA PLANES

- Produce gridded data sets for this procedure in GEMPAK. The area enclosed by the boundaries of the gridded data set should be about 5 degreees larger on each side than the satellite and topography images. This allow for the remapping process.
- Make note of the maximum and minimum heights in the grided data file. Match these heights with the corresponding temperature on a representative rawinsonde sounding. Convert these temperatures into IR pixel values.
- Create navigation files for the data image using the program NAVGEN.
- Use the data plane image and the navigation files as input to the GEMPAK program REMAP. The latitude and longitude of the remapped image bounds should match those in the topography and cloud image files.
- Run the output mercator projected image through DEFSCT, INTCLD, and CLDGEN as previously described. In INTCLD enter a base height of "-999". Delete the DEFSCT.DAT file ater each program is executed.
- Rename the .BLO and .LOW files output from CLDGEN as the ".BMI" and ".MID", or ".BHI" and ".HGH" file, respectively.
- Run MERGER.
- Run DISPLAY as previously described.

APPENDIX B

PREPROCESSING OF SATELLITE DATA

The satellite data originating at NEPRF is on 800 bpi tapes. In order to read the tape files onto the VAX computer, they must be converted into 1600 bpi. This process occurs on the NPS UNIX computer. The list below describes steps used in this process that may be helpful.

- Log onto the UNIX computer using the "GUEST" account. The password may be obtained from the UNIX system manager.
- Create a directory to temporarily contain the satellite and navigation files using the following command: "MKDIR TEMP". Any directory name can be used in place of the "TEMP" entry.
- Change to the "TEMP" directory by issuing the command "CD TEMP".
- After mounting the tape on the UNIX tape drive enter the following command: "dd if=/dev/rmt4 of=fname". "fname" should be replaced with a unique name for each file read off the tape. The above command must be issued for each tape file. The UNIX system will prompt the user for a new filename after each previous file has been read in. This process reads in the 800 bpi image and navigation files to the files named by the user, in the directory created at the beginning. Note: UNIX interprets upper and lower case letters differently. User's should enter the commands in lower case.
- Rewind the tape.
- Make sure the tape "write ring" is on the data tape.
- Read each disk file back onto the tape using the command "dd if=fname of=/dev/rmt12". This writes the files back to tape in 1600 bpi form. Similar to before, "fname" should be substituted with the name of the image or navigation file to be written out to tape.
- Rewind the tape and log off the UNIX computer using the command "logout".
- Log onto the VAX computer.
- Enter the command "ALLOCATE MFA0:" to reserve the VAX tape drive for use. This ensures that another user will not accidentally write to the satellite data tape and erase files.
- Assign the MFA0 device as a tape reading device using the command "ASSIGN MFA0: TAPE".
- Enter "MOUNT/FOR/DEN=1600 MFA0:".
- Enter "RUN TAPES: MAGTODSK". This command executes a VAX utility to read magnetic tape disk files sequentially to disk files.
- In response to the record length prompt, the user should enter a "N".
- The input device name is "MF0:". Note that there is no "A" as in "MFA0".
- Specify the desired output disk file names when prompted. This must be done for each tape file.

- Enter the command "DISMOUNT MFA0:" and then "DEALLOCATE MFA0:". This first rewinds the tape and then makes the tape drive available for other users.
- After the images and navigation files are determined to be correct. The user must log back onto the UNIX computer and delete the directory containing the temporary image and navigation files.

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